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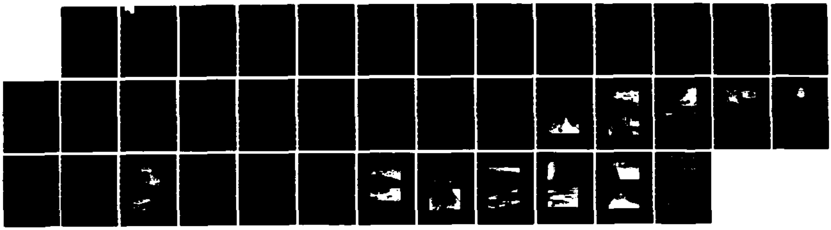

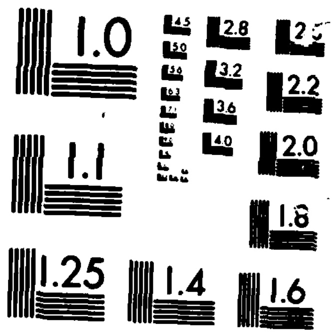

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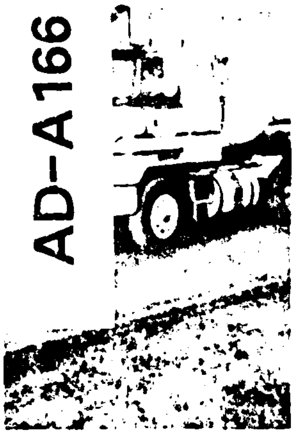

GEOTECHNICAL LABORATORY

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ASPHALT PAVEMENT RECYCLING PRIMER

by

Timothy W. Vollor

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

> This report is intended to familiarize the reader with the different asphalt pavement recycling techniques. Asphalt pavement rehabilitation using recycling techniques has proven itself to have many applications and to be a cost-effective method to be considered when planning a rehabilitation project.

The report discusses three types of asphalt pavement recycling

(Continued)

20. ABSTRACT (Continued).

Cont.

techniques: surface recycling, cold-mix recycling, and hot-mix recycling. A brief description of each technique is given with the advantages and disadvantages associated with them. Some of the incentives for using pavement recycling are discussed and a list of available guide specifications and a standard practice manual is given. Keywords: Asphalt cement.

PREFACE

This study was conducted by the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, for the Office, Chief of Engineers (OCE), US Army, under O&M,A. Mr. R. L. Williams was the Technical Monitor for OCE. The work was performed from April 1983 through July 1985. The report was prepared under the project entitled "Pavement Recycling Primer."

WES personnel actively engaged in the conduct of this project included: Mr. H. H. Ulery, Jr., Dr. T. D. White, Mr. J. W. Hall, and Dr. E. R. Brown, Pavement Systems Division (PSD), GL. The work was conducted under the general supervision of Dr. White and Mr. Ulery, former Chief and Chief, respectively, PSD, GL, and Dr. W. F. Marcuson III, Chief, GL. Messrs. W. N. Brabston (PSD) and C. C. Calais, Publications and Graphic Arts Division (P&GAD), were instrumental in developing the illustrations. This report was written by Mr. T. W. Vollor, PSD, and edited by Mr. Robert A. Baylot, P&GAD.

Director of WES was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
inches	2.54	centimetres
tons (2,000 pounds, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use $K = (5/9)(F - 32) + 273.15$.

ASPHALT PAVEMENT RECYLING PRIMER

PART I: INTRODUCTION

1. Recycling as defined in "Asphalt Hot-Mix Recycling" (Asphalt Institute 1981) is "the reuse, usually after some processing, of a material that has already served its first intended purpose." Recycling of flexible pavements as used herein is defined as "the reuse, after a certain processing, of bituminous pavement materals that have already served in a pavement structure."

2. Recycling of pavements is no longer an experimental method of rehabilitating a pavement, but a proven alternative rehabilitation method where cost-effectiveness should be examined on a case-by-case basis wherever pavements require rehabilitation. The following considerations have influenced the rapid growth of recycling.

a. Environment. The reconstruction of old pavements often consists of removing the old pavement material because the pavement had structurally failed, existing drainage patterns and structures had to be maintained, dead load on bridge or clearance in tunnels and under bridges had to be maintained, and for the other reasons. The removed old pavement material was unsightly (Figure 1) and proper disposal was expensive. Recycling of old pavement makes use of inexpensive available material and eliminates the disposal problem.

b. Material cost. The amount of asphalt and high-quality aggregate available for construction is limited. Because these supplies are limited and costs have increased including the high cost of fuel and equipment required to haul the asphalt and aggregate to jobsites, recycling has become more desirable.

c. Technology and equipment. The increased interest in recycling pavements has brought about the development of technology and equipment for recycling (such as the cold-milling machine shown in Figure 2) that results in an overall reduction in cost when recycled materials are used.

d. Emphasis on rehabilitation. With the winding down of the construction of the interstate highway system and the high cost of right-of-way, new construction of roadways and airports is declining. The rehabilitation of existing facilities is being

emphasized. This has encouraged the use of recycling as a means of stretching the dollars being provided for this work.

3. Generally, three categories of asphalt concrete (AC) recycled pavements are recognized. These categories are outlined as follows:

a. Surface recycling.

(1) Heater-planer-scarifier-overlay.
(2) Cold milling.
(3) Rejuvenating.

b. Cold-mix recycling.

(1) In-place processing.
(2) Fixed plant processing.

c. Hot-mix recycling.

(1) Drum mixer processing.
(2) Conventional batch or continuous feed plant processing.

Many recycling jobs may use more than one of the processes outlined above.

PART II: SURFACE RECYCLING

4. Surface recycling is considered when the structural integrity of the pavement structure is satisfactory, and rehabilitation of the surface is needed to correct defects such as weathering, low skid resistance, and minor roughness. Three surface recycling processes are discussed in the following paragraphs.

Heater-Planer-Scarifier-Overlay

5. The heater-planer-scarifier-overlay process is one of the first successful surface recycling processes to have been used. The process consists of heating the surface of the pavement to a depth of to 1 to 2 in. and then scarifying (Figure 3) and/or planing (Figure 4), followed by a thin overlay. This process is used to smooth the surface and break up the crack pattern before the pavement is overlaid, reducing the overlay thickness required.

6. Disadvantages of the heater-planer-scarifier-overlay operation are air pollution and possible poor workmanship. Air pollution results from burning the asphalt cement during heating, especially when using direct flame (Figure 5). The use of indirect heat combined with experience in using the process can minimize the pollution, but the problem still exists. The heater-planer-scarifier-overlay operation requires special knowledge and fully qualified, experienced operators. With the advent of the cold-milling machine and hot recycling techniques, the use of this procedure has declined.

Cold Milling

7. The cold-milling process is used to texture the surface (Figure 6) and/or shape the pavement without the use of heat.* Equipment is available which can cut the bituminous pavement to a desired depth from 1/4 to 5 in. or maintain a desired grade and slope (Figure 7). This process is used to improve the skid resistance and/or smoothness of the pavement.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

8. Several disadvantages are associated with cold-milled surfaces. Cold-milled bituminous pavement surfaces may experience raveling if not overlaid or sealed, and a cold-milled surface has a rough texture which may give undesirable ride qualities due to excessive noise (Figure 8).

9. Cold milling of pavements has grown in popularity even though the initial equipment investment is quite high. Some of the reasons for this popularity are as follows:

- a. Versatility. The process may be used to remove both bituminous and portland cement concrete.
- b. Control. As stated earlier, it has grade and slope control or can be controlled by depth of cut.
- c. Pollution. Because the process does not use heat, air pollution is not a problem.
- d. Traffic control. The interruption of traffic is minimal.
- e. Additional Uses. Besides being used in surface recycling, it is useful in cold-mix and hot-mix recycling processes.

Rejuvenators

10. Rejuvenators have been used extensively in surface recycling and are sprayed directly on the surface of a bituminous pavement using a conventional asphalt distributor (Figure 9). The petroleum-based rejuvenator penetrates into the surface of the bituminous pavement (1/4 to 1/2 in.) to soften the asphalt binder and improve the binder properties. If properly used, a rejuvenator will retard the loss of surface fines and reduce the amount of cracking, thus extending the life of the pavement 3 to 5 years.

11. Several disadvantages or limitations should be considered before using a rejuvenator on a pavement:

- a. Skid resistance is temporarily reduced (Figure 10).
- b. Rejuvenators cannot be used over surface treatments such as slurry seals, porous friction courses, and asphalt rubber (Figure 11).

c. Experienced personnel are required.

d. The pavement must be structurally sound.

12. Rejuvenators may be effectively used to extend the life of an AC pavement. However, limitations of rejuvenators should be considered carefully before use, and a qualified person should oversee the construction. Test sections should be used to determine the application rate.

PART III: COLD-MIX RECYCLING

13. Cold-mix recycling involves the reuse of existing pavement materials by reprocessing them and adding additional binder and/or lubricant without the use of heat. When pavement deterioration is so bad that the conventional overlay thickness required is not economical or is prohibited by existing grades, cold-mix recycling should be considered. Also, if a secondary road needs rehabilitating, cold-mix recycling should be considered as a surfacing since it will withstand light traffic. A flow diagram for cold-mix recycling is shown in Figure 12.

Removal of Existing Pavement

14. The asphalt concrete to be recycled must be removed to the desired depth or grade. This removal is usually accomplished by a cold-milling machine but can be accomplished with rippers and a front-end loader. If cold milling is used, the size of the chunks of the reclaimed asphalt pavement (RAP) is usually satisfactory and further crushing to meet size requirements is not necessary. However, if the RAP is obtained by ripping or a similar method (Figure 13), further crushing, either in a central plant or in-place, will be necessary. The RAP may be used by itself with a lubricant or binding agent, or virgin aggregate may be combined with the RAP along with a lubricant or binding agent.

Modifiers Used

15. In the past, three types of modifiers have been added to the RAP to produce recycling cold mix. These three modifiers have included water, asphalt emulsion, and recycling agent.

16. When water is added to RAP, it provides lubrication to facilitate compaction. The optimum water content should be determined by laboratory tests and should be the water content that provides the highest dry density.

17. Asphalt emulsions (usually SS-1 or CSS-1) are added to the RAP to provide a lubricant and to add additional binder to the RAP material.

However, RAP material normally contains approximately the correct amount of asphalt binder from the initial construction. Therefore, only a small percent of emulsion can be added and care must be taken not to add too much, causing an unstable mix. Since the asphalt emulsion is both a lubricant and binder, the amount of emulsion to be added is limited. The addition of water may be required in conjunction with the emulsion to provide the proper amount of lubricant for compaction.

18. A recycling agent is sometimes added to RAP to provide lubrication and some binding qualities and also to modify the properties of the asphalt binder. A recycling agent is needed when the asphalt cement in the RAP has aged causing the RAP to be hard and brittle. The recycling agent can be used to restore some of the original desired properties of RAP binder.

Central Plant or In-place Production and Placement

19. Cold-mix recycling is generally produced by either in-place processing or by removing the old pavement and taking it to a central plant for processing. Both methods have been used with success.

20. In-place processing has been used quite frequently. For in-place processing the old pavement is broken up, crushed, or pulverized in place (see Figure 14). When the correct gradation of the broken-up pavement is obtained, the modifiers are added and mixed, and the mixture is then spread to the proper grades and compacted. An advantage of this procedure is that minimal transportation of the material is required.

21. In central plant processing, the broken-up pavement is taken to a mixing plant where it is mixed with the proper modifiers and transported back to the jobsite, spread, and compacted. The advantage to this process is that a more consistent mix is obtained, resulting in a more durable pavement.

Cold-Mix Recycling Typical Application

22. An example where cold-mix recycling could save money over other alternatives is the repair and strengthening of an existing deteriorated

pavement to carry additional traffic volumes and/or loads. For example, the sign indicates an additional 3 in. of AC are needed. If the 3 in. of AC are placed over the existing deteriorated pavement, the new overlay will deteriorate rapidly because of the reflection of the cracks in the old pavement through the overlay. Assuming there are 3 in. of existing asphalt concrete, two alternative solutions are available: (a) removal of the existing 3 in. of asphalt concrete and replacement with 6 in. of hot-mix asphalt concrete, or (b) removal of the 3 in. of asphalt concrete and recycling of this material to produce 3 in. of cold-mix recycling and overlaying with 3 in. of hot-mix asphalt concrete. In the second case, a considerable savings could be realized due to the reuse of materials in recycling and minimization of the reflective cracking problem.

PART IV: HOT-MIX RECYCLING

23. Hot-mix recycling involves the reuse of the existing pavement structure by taking up the old pavement; crushing the pavement, if needed; adding virgin aggregate, asphalt, and/or recycling agent; mixing the heated materials; and placing using the same procedures as those for conventional hot mix. This procedure can produce an asphalt concrete mix having the same quality as that of a conventional asphalt concrete mix. Figure 15 is a flow diagram for hot-mix recycling.

Removal of Existing Pavement

24. The pavement to be recycled should be removed by use of a cold-milling machine or removed with ripper tooth and crushed. Generally the cold-milling machine is used. If a cold-milling machine is used properly, the RAP material will generally not need crushing. Another desirable feature of cold milling is the ability to leave approximately 1/2 in. of the asphalt concrete over the base course to prevent damage to the base course and provide a waterproof working surface. When the pavement is removed and is properly sized, it should be stockpiled in such a way as to ensure proper mixing of the RAP material to obtain a uniform material in the stockpile.

Plant Production and Placement

25. Recycled asphalt concrete is generally produced using either a drum mixer or a batch plant which has been designed or modified to produce recycled mixtures.

26. The drum mixer is used to produce the majority of the recycled asphalt mixtures being produced. The procedure used by a drum mixer is shown graphically in Figure 16. The new aggregate is introduced at the high side of the drum near the flame. This allows the new aggregate to absorb much of the heat and act as a shield to prevent the flame from burning the RAP material. The RAP material is added halfway down the drum where the new asphalt binder and recycling agent also are added. The new aggregate, RAP material, new asphalt, and recycling agent also are added. The new aggregate, RAP material,

new asphalt, and recycling agent, if used, are mixed in the lower half of the drum so that the mix, which exits from the drum, is a hot recycled mix ready for placement.

27. The batch plant is also used to produce recycled asphalt concrete mixtures. The procedure used in a batch plant is shown graphically in Figure 17. The new aggregate is heated in the dryer drum to approximately 400° to 600° F. The RAP material is placed on top of the heated new aggregate in the weight hopper at which point heat transfer begins between the new aggregate and the RAP material. This heat transfer is continued in the mixer where the new asphalt cement, reclaiming agent, or both are added. After mixing, the mix should be at the desired temperature for hauling and ready for placement.

28. A drum mixer can be used to produce asphalt mixtures using up a maximum of 70 percent reclaimed mixture. However, to ensure that quality of the mix is controlled, the amount of reclaimed asphalt concrete used in the drum mixer should not exceed 60 percent. The batch plant is limited to 50 to 60 percent of RAP material because 40 to 50 percent new superheated aggregate is needed to obtain sufficient heat transfer to the RAP.

29. Standard pavement laydown and compaction equipment is used to place a recycled asphalt mix (Figure 18). The same procedures and quality control measures should be implemented with the recycled asphalt mix as used with a conventional hot mix.

Hot-Mix Recycling Typical Application

30. An example where hot-mix recycling could save over other alternatives is the repair of a badly cracked 3-in.-thick concrete pavement which has to be removed and replaced. A design indicates that 3 in. of asphalt concrete pavement is adequate for future uses.

31. Two alternative solutions are available:

a. Removing the existing 3 in. of asphalt concrete and replacing it with 3 in. of hot-mix asphalt concrete.

b. Removing the existing 3 in. of asphalt concrete and recycling this material to produce 3 in. of recycled hot mix. In this case, a considerable savings could be realized by recycling.

PART V: INCENTIVES FOR RECYCLING

32. The process of rehabilitating a pavement by recycling has grown in popularity in recent years. The process has grown from a research phase to a conventional method to be considered when rehabilitating a pavement. In order to be a successful method of rehabilitating a pavement, recycling must be proven cost-effective.

Cost Considerations

33. The cost of materials used in asphalt concrete pavements (asphalt cement and aggregates) has greatly increased in recent years. Also, the cost of transporting these materals has increased greatly.

34. As an exmaple, consider one truck loaded with 20 tons of RAP materials. The asphalt content in the RAP would be from 5 to 6 percent in most cases. If the asphalt content were 5 percent, there would be 1 ton of asphalt in the load. The cost of asphalt cement varies but will be about $200.00 per ton. Therefore, this truckload of RAP is worth $200.00 for the asphalt cement alone.

35. The fuel cost for hauling new aggregate and new asphalt cement from their source to the construction site also is an important cost consideration. The longer the haul distances, the higher the cost. Therefore, if the amount of material to be hauled can be reduced, there will be a decrease in cost.

Environmental Considerations

36. Some of the first reasons used to promote recycling were environmental. A design calling for removal of old bituminous pavement or the abandonment of a stretch of road results in an unsightly appearance (Figures 19 and 20) and proper disposal is expensive.

37. There is not an unlimited supply of natural resources available for road construction. This was made clear during the oil embargo of the

1970's. Not only is there a limited supply of oil available, but there is also a limited supply of good aggregate. In many areas of the United States satisfactory aggregate must be hauled long distances, sometimes in the hundreds of miles.

Design Advantages

38. Recycling has the following design advantages that should be considered when designing a pavement rehavilitation program:

- a. Recycling eliminates or retards reflective cracking (Figure 21).
- b. It allows dead loads on bridges to be maintained (Figure 22).
- c. Recycling allows clearances through tunnels and under bridges to be maintained (Figure 23).
- d. Drainage patterns may be maintained (Figure 24).
- e. Recycling allows existing grades to adjoining surfaces to be met (Figure 25).
- f. Rehabilitation of only that part of the pavement which needs repair is allowed (Figure 26).
- g. Base courses may be repaired.
- h. Pavements may be strengthened for either increased loads or increased traffic (Figure 27).
- i. Recycling offers improved surface conditions, such as skid resistance, smoothness, and weather resistance.

PART VI: AVAILABILITY OF GUIDE SPECIFICATIONS AND STANDARD PRACTICE MANUAL

39. The following Departments of the Army and Air Force standard practice manual and US Army Corps of Engineers guide specifications (CEGS) are available:

- a. TM 5-822-10/AFM 88-6, Chapter 6, "Standard Practice Manual for Pavement Recycling."
- b. CEGS-02590, "Recycled Asphalt Concrete Intermediate and Wearing Course for Airfields, Heliports, and Heavy-Duty Pavements (Central Plant Hot Mix)."
- c. CEGS-02591, "Cold-Mix Recycling."
- d. CEGS-02597, "Heater-Planer and Heater-Scarifier Procedures for Bituminous Pavements."
- e. CEGS-02598, "Cold Milling of Pavements."
- f. CEGS-02599, "Bituminous Rejuvenation."

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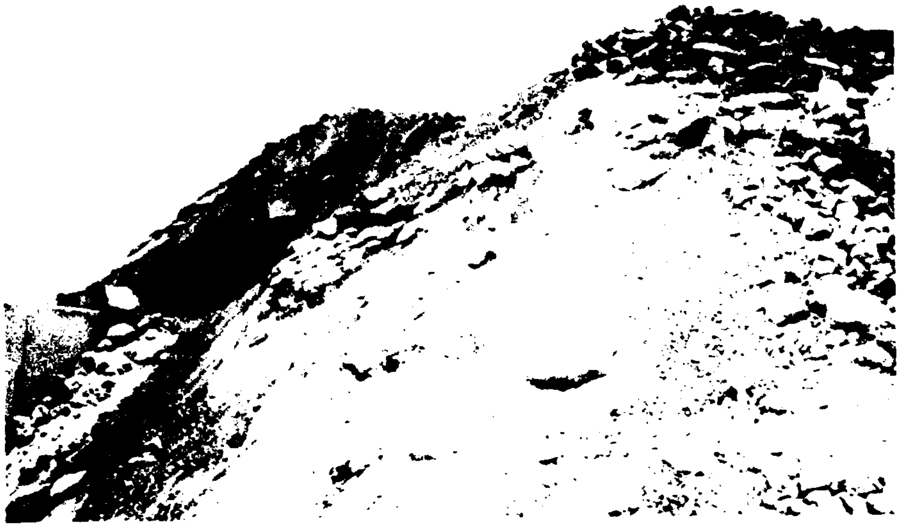

Figure 1. Stockpile of old pavement

Figure 2. Cold-milling machine

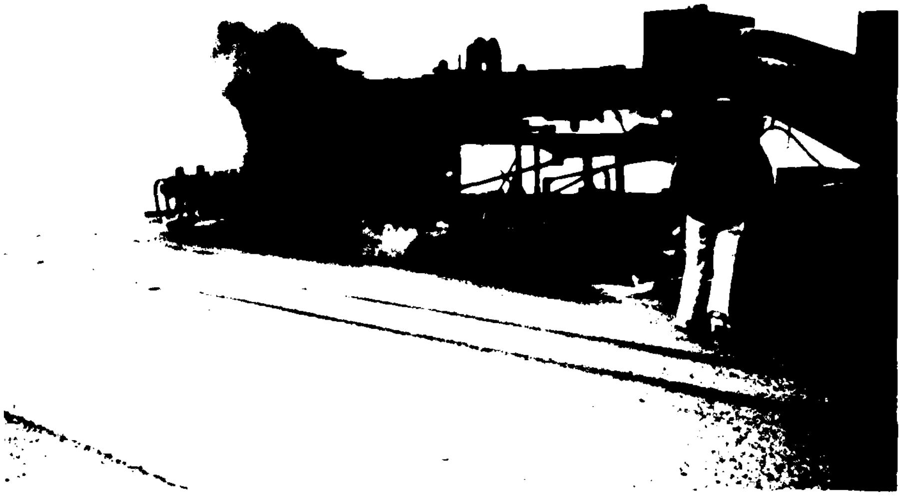

Figure 3. Heating and scarifying operation

Figure 4. Planer operation following a heater-scarifier

Figure 5. Example of air pollution which can occur during heating of pavement

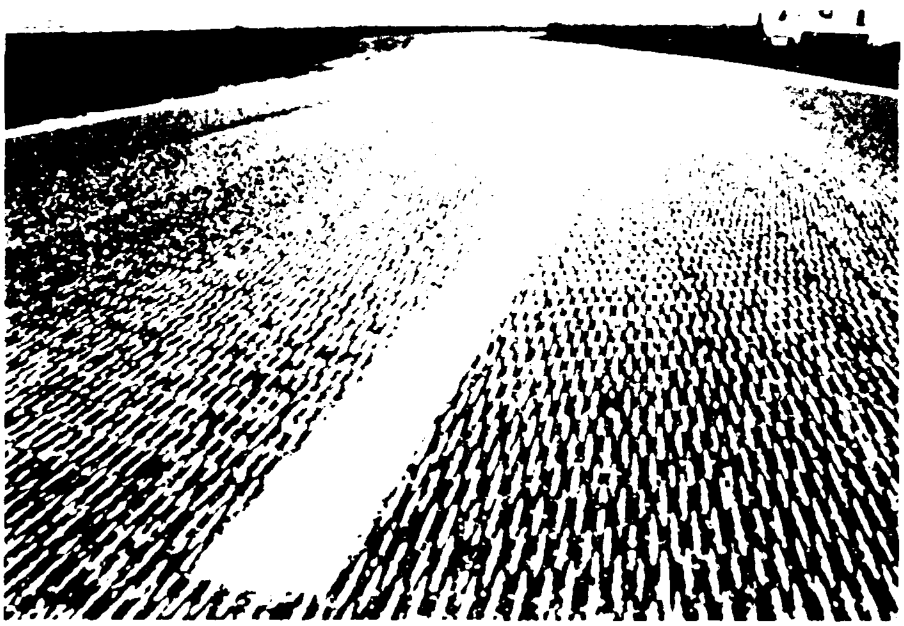

Figure 6. Surface texture produced by cold milling

Figure 7. Example of equipment (cold-milling machine) used to remove pavement to desired depth, grade, and/or slope

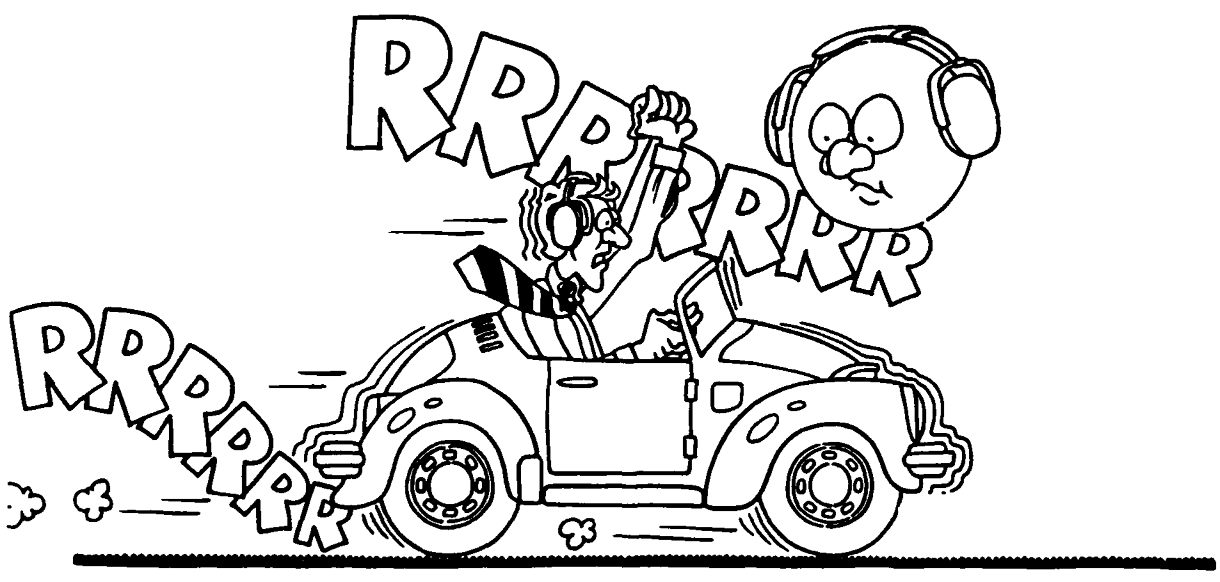

Figure 8. The noisy ride of a cold-milled surface

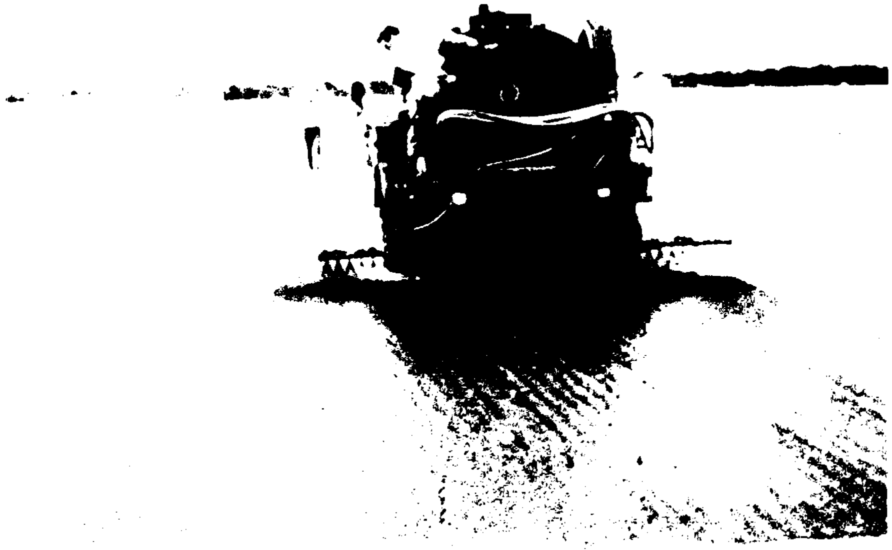

Figure 9. Asphalt distributor used to spray a rejuvenator

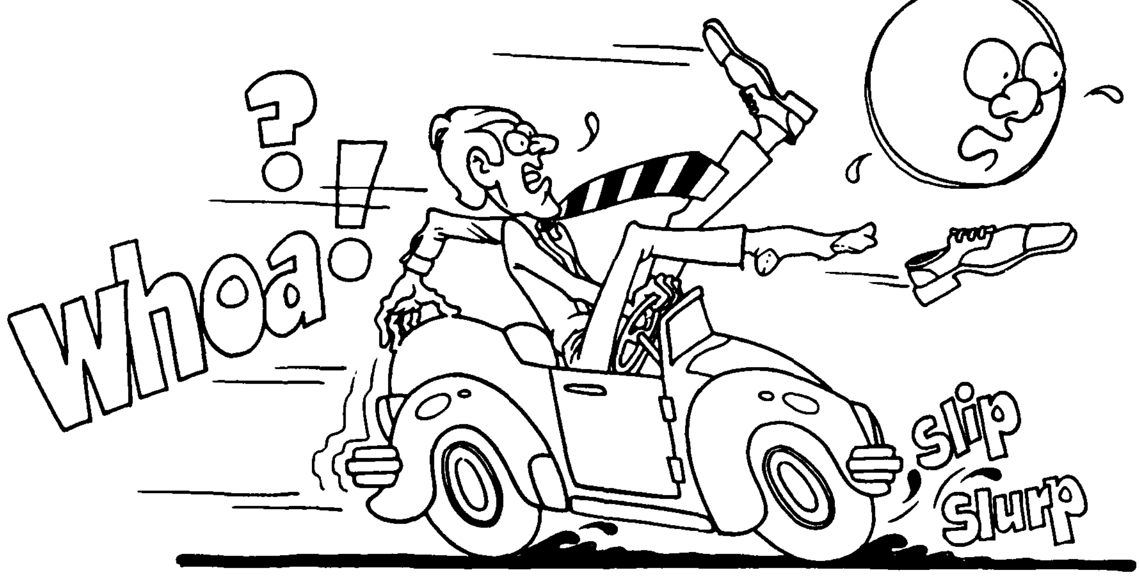

Figure 10. Rejuvenators cause temporary loss of skid resistance

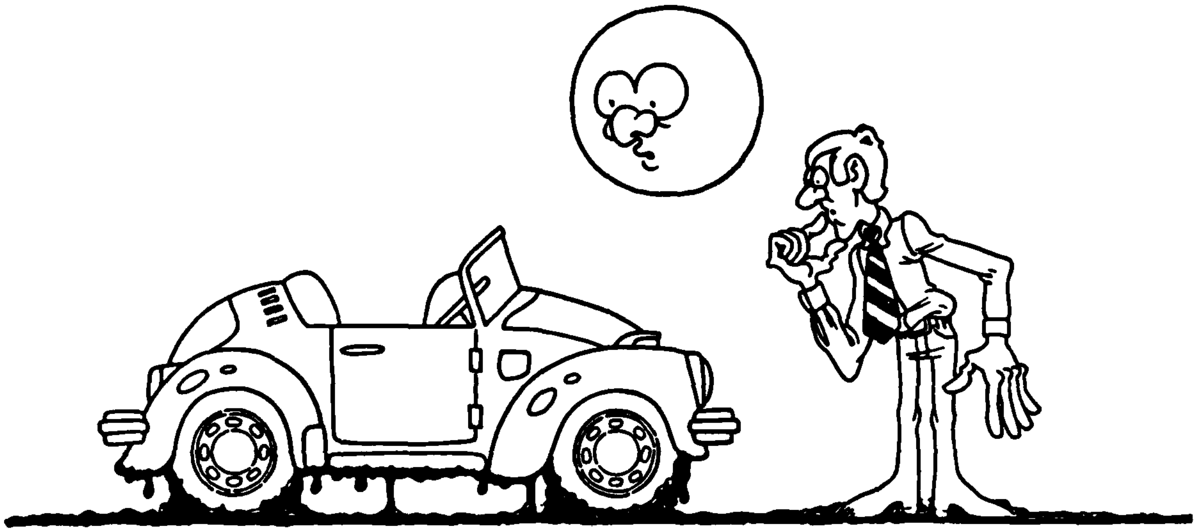

Figure 11. Rejuvenators applied to asphalt pavement surfaces which have a high asphalt cement content will cause the above problem

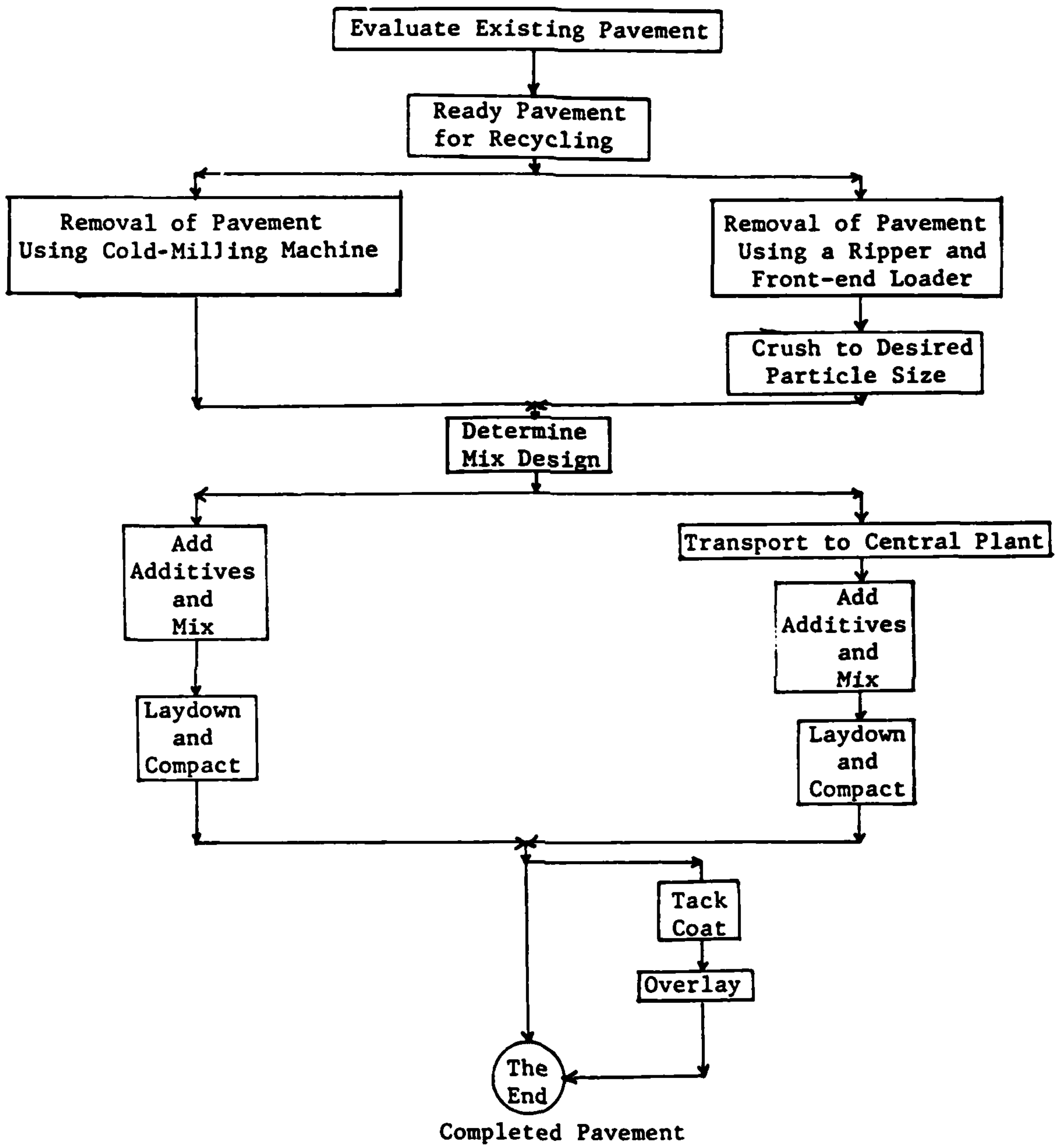

Figure 12. Cold-mix recycling flow diagram

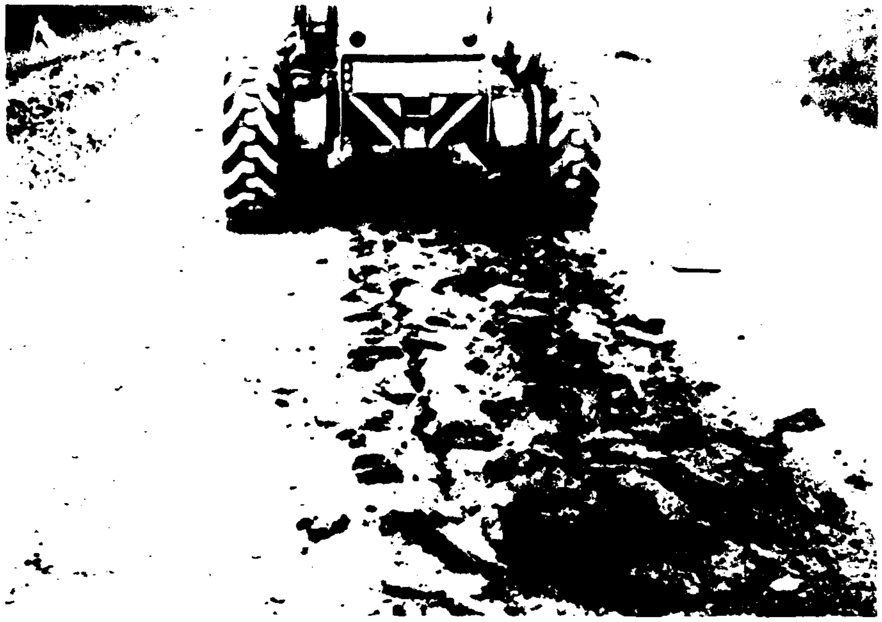

Figure 13. Ripping up pavement in preparation for cold-mix recycling

Figure 14. Mixed-in-place cold-mix recycling

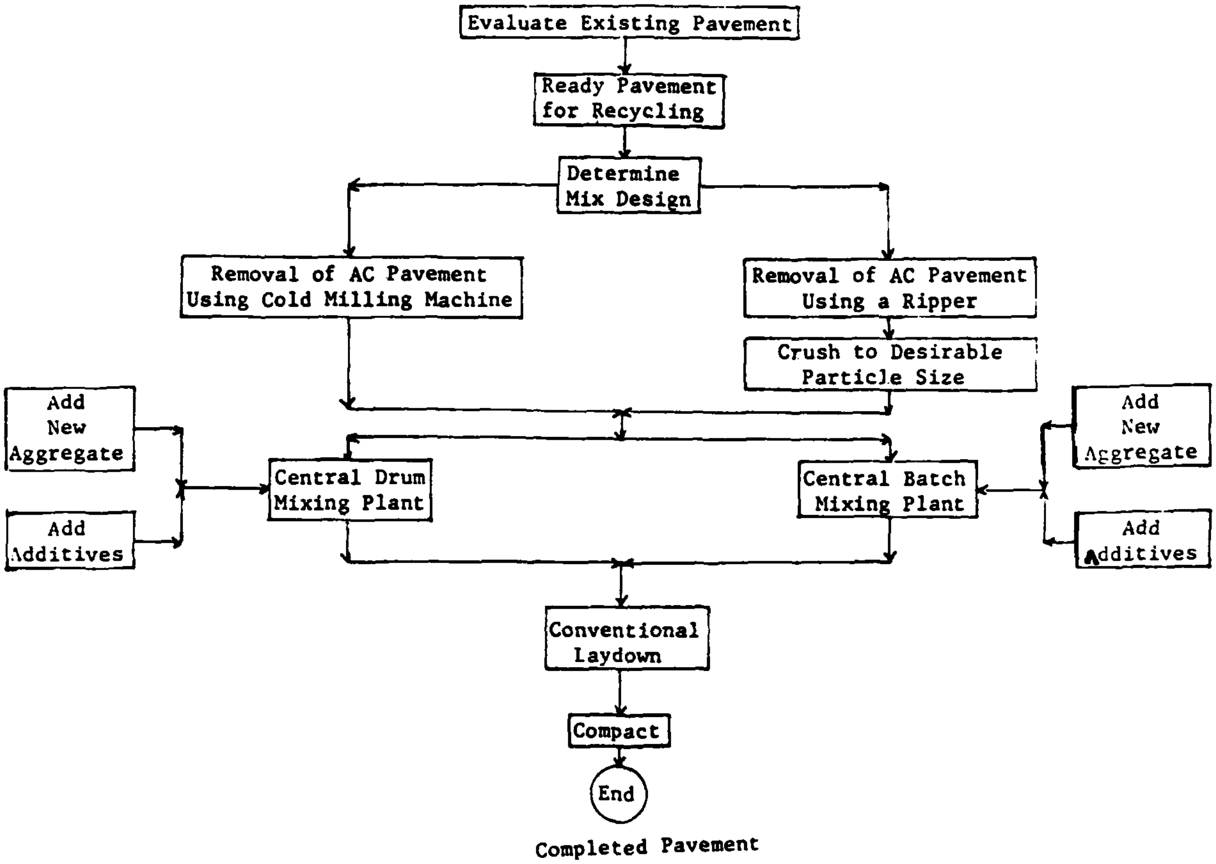

Figure 15. Hot-mix recycling flow diagram

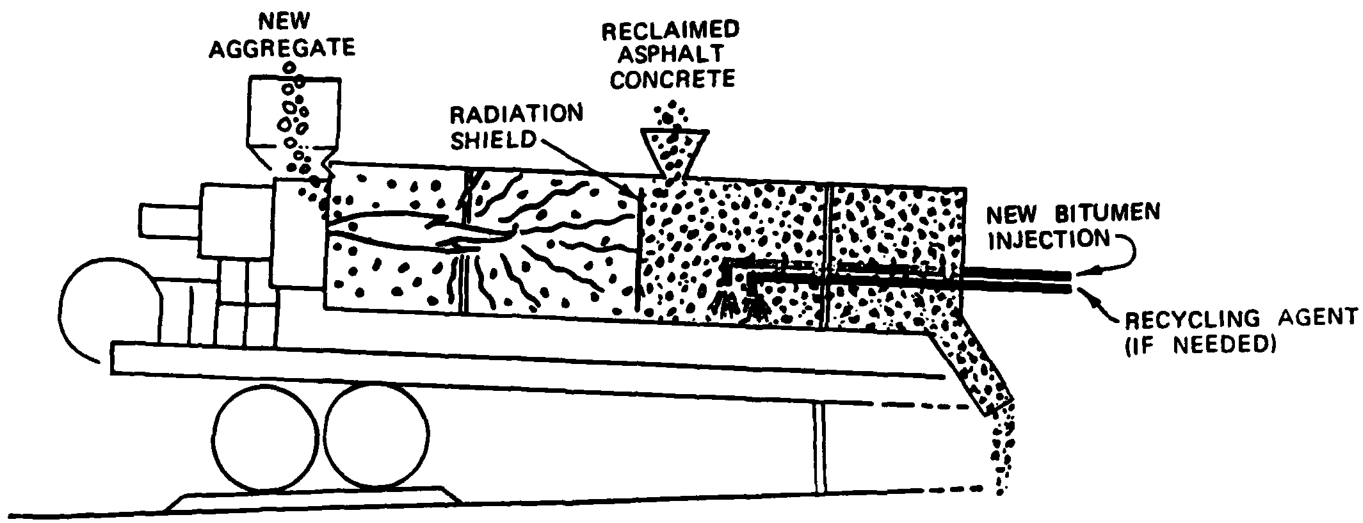

Figure 16. Drum plant

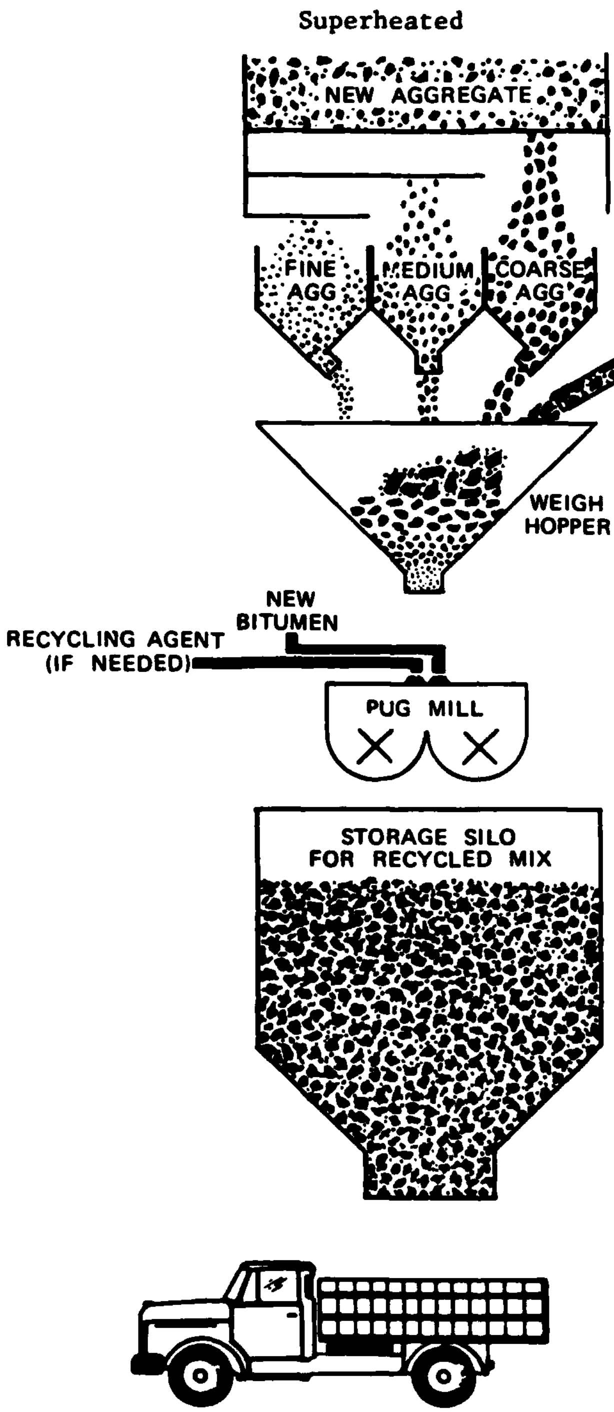

Figure 17. Batch plant

Figure 18. Rollers compacting a hot recycled pavement

Figure 19. Discarded bituminous pavement

Figure 20. Abandoned road is an eyesore

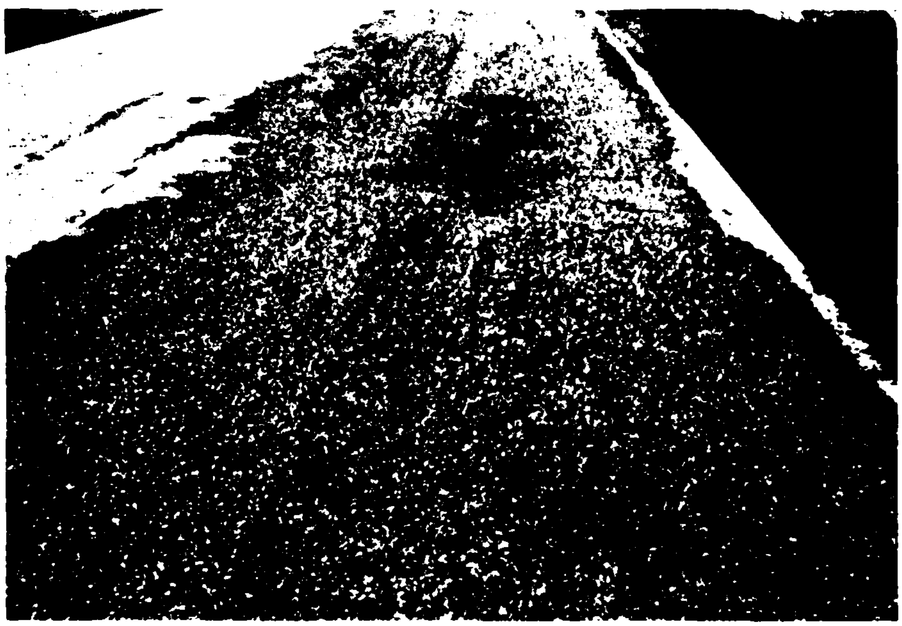

Figure 21. A potential reflective crack

Figure 22. Removing pavement from bridge to maintain allowable dead load

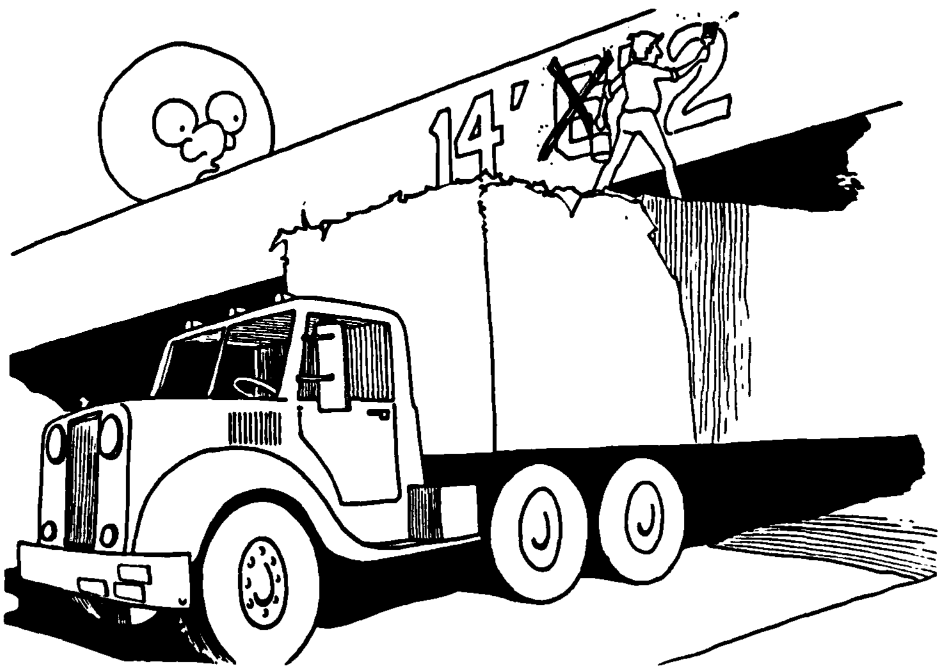

Figure 23. A 4-in. overlay can cause problems where critical clearances are involved

Figure 24. Asphalt overlay placed over concrete curb and gutter

Figure 25. Removal of old pavement and recycling allows the grade of aircraft fueling points on parking apron to be maintained

Figure 26. Recycling a truck lane on a four-lane highway

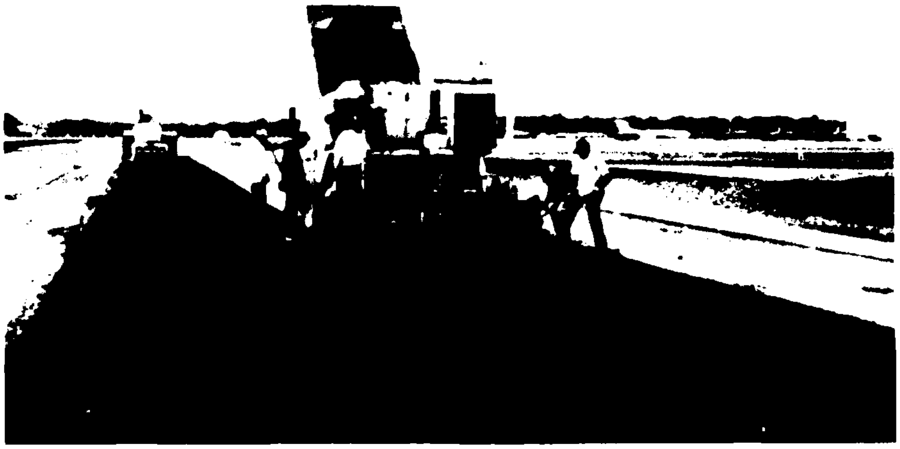

Figure 27. Cold recycling in-place pavement using central plant, then overlaying with conventional hot-mix

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